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Lithium-Ion Life Expectancy Verficiation Guidelines for Transformational Communication Satellite System (TSAT)

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Prepared by

W. H. HWANG AND V. J. ANG
Electronics and Photonics Laboratory
Laboratory Operations

Prepared for

SPACE AND MISSILE SYSTEMS CENTER
AIR FORCE SPACE COMMAND
2430 E. El Segundo Boulevard
Los Angeles Air Force Base, CA 90245

20051129 035

Space Program Operations

THE AEROSPACE CORPORATION
El Segundo, California

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

José Roberto Silva.

Maj. Jose R, Silva
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14. ABSTRACT

Guidelines are provided for the Transformational Communication Satellite System (TSAT) mission relative to life-expectancy verification of lithium-ion cells. Conditions and associated risks are presented to facilitate a decision to include or adopt the technology, or a decision to launch before there are sufficient data to conclusively verify life expectancy.

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Contents

1. Introduction

The goal of this technical report is to provide guidelines for life-expectancy verification of lithium-ion cells in the minimum time for a TSAT mission. Conditions, time relative to the life expectancy requirement or goal, and associated risks are presented to facilitate a decision to include or adopt the technology or a decision to launch before there are sufficient data to conclusively verify life expectancy.

1.1 Limitations of Scope

These guidelines are intended for life expectancy verification at the cell level.

- The guidelines pertain only to life expectancy verification and do not address performance and structural margins, dimensional requirements, compatibility to pre-launch, launch and space environments, manufacturability, testability, maintainability, reliability, and compatibility with system safety. All of these factors shall be considered in assessing cell and battery qualification.

- The life expectancy verification of a specific cell design can be used in assessing life expectancy verification of batteries made from those cells. In such a battery-level assessment, the life expectancy of all individual battery components as well as any interactions between components shall be considered. Appropriate battery and power subsystem designs may result in different risk assessments at the battery or subsystem levels.

- These guidelines do not include verification of pre-launch shelf life or total service life, which includes shelf life.

2. Approach

The approach is basically the same one used for the two previous space vehicle battery cell technologies, nickel hydrogen and nickel cadmium. Verification of life expectancy will be made for each specific cell design and each mission since life can depend on cell design and mission condition. Data for different designs and mission conditions may be used in life verification assessments, subject to the constrains described below. On-orbit data, data from real-time tests, where the time and current profiles of cell discharge and charge exactly match those of the mission, and data from accelerated tests can be used to develop models and projections. Accelerated tests can be accelerated in time and/or in cell degradation, and results from these tests should be related to tests under real-time conditions on a sound technical basis. Data from real-time and accelerated tests should include electrical performance data and data from destructive physical analysis of tested cells. Model projections should be based on real-time data, which is the most reliable data for life expectancy verification, as well as accelerated test data. A decision to include or select a technology or design for a mission before there are sufficient data to conclusively verify life expectancy may be made, with the expectation that continued testing after the decision is made should provide data that could subsequently result in a lower risk assessment. In addition, the pursuit of a dual path with a more established design or technology could be considered to reduce program risk.

2.1 Data for Different Cell Designs or Different Mission Conditions

Lithium-ion cell technology is still changing rapidly, and the requirements of different missions can result in different degradation rates. A change in cell design or mission condition will require an updated or modified analysis, where the life expectancy risk assessment can be less than or equal to that of a previously established assessment.

- A change in cell design includes but is not limited to the following:
  - Positive electrode composition, raw material (including binder), loading density, foil, or dimension
  - Negative electrode composition, raw material (including binder), loading density, foil, or dimension
  - Electrolyte composition
  - Separator composition or dimension
  - Cell stack dimension or compression
  - Cell case size
- A change in mission condition includes but is not limited to the following:
  - Maximum or average discharge load

- Number of discharges per time period
- Charge control method or limit
- Maximum, minimum, or average temperature by more than 3°C

- A change in cell manufacturing location will also require an updated or different analysis.

2.2 Updated or Modified Analysis

An updated or modified analysis (relative to an established assessment) will result in a shorter life expectancy assessment than that of the previously established assessment, with one exception described below. Any analysis needs to have a firm technical basis and be grounded with orbital or test data.

An updated or modified analysis can result in the same life expectancy compared to that of a previously established assessment if the following three conditions are met

- There are orbital and/or ground test data that demonstrate that the direction of such a change or difference results in longer or the same life expectancy
- There are no orbital and/or ground test data to support that the direction of such a change or difference results in shorter life expectancy.
- Technical analysis of the specific change or difference, based on data and analysis of degradation and failure modes and effects, supports that the specific change or difference is expected to result in longer or the same life expectancy.

3. Risk Assessments

Risk assessments using three types of information are described below: (1) using only real-time data, (2) using a combination of real-time data and accelerated test data where a quantitative relationship between accelerated and real-time testing has not yet been universally accepted by the space battery community, and (3) using a combination of real-time data and accelerated test data where a model quantitatively relating accelerated and real-time testing has been universally accepted by the space battery community.

3.1 Assessment of Risk Using Only Real-time Data

When only real-time data, with appropriate time and current profiles, are used, the risks associated with the assessment are the following:

- If the real-time data demonstrate 60% of the mission life or longer without any cell failure, subject to the sample size considerations described below, and the projected life values are above the mission life requirement or goal, the risk assessment shall be "medium" or higher. Whether the risk assignment is "medium" or at some higher risk level depends on the projected life margin and the data dispersion.
- If the real-time data demonstrate 70% of the mission life or longer without any cell failure, subject to the sample size considerations described below, and the projected life values are above the mission life requirement or goal, the risk assessment shall be "low-medium" or higher. Whether the risk assignment is "low-medium" or at some higher risk level depends on the projected life margin and the data dispersion.
- If the real-time data demonstrate 85% of the mission life or longer without any cell failure, subject to the sample size considerations described below, and the projected life values are above the mission life requirement or goal, the risk assessment shall be "low" or higher. Whether the risk assignment is "low" or at some higher risk level depends on the projected life margin and the data dispersion.

3.2 Assessment of Risk Using a Combination of Real-time and Accelerated Test Data for Model Projections without Universally Accepted Quantitative Relationship between Accelerated and Real-time Testing

If a combination of real-time and accelerated test data are used for model projections, the model projection methodology and use of accelerated test data have a sound technical basis, including all degradation modes, but the quantitative relationship between real-time and accelerated testing has not been established or has not been universally accepted by the space battery community, the risks associated with the assessment are as follows:

- If the real-time data demonstrate 50% of the mission life or longer without any cell failure, subject to the sample size considerations described below, and the projected life values are above the mission life requirement or goal, the risk assessment shall be "medium" or higher. Whether the risk assignment is "medium" or at some higher risk level depends on the projected life margin and the data dispersion.
- If the real-time data demonstrate 65% of the mission life or longer without any cell failure, subject to the sample size considerations described below, and the projected life values are above the mission life requirement or goal, the risk assessment shall be "low-medium" or higher. Whether the risk assignment is "low-medium" or at some higher risk level depends on the projected life margin and the data dispersion.
- If the real-time data demonstrate 80% of the mission life or longer without any cell failure, subject to the sample size considerations described below, and the projected life values are above the mission life requirement or goal, the risk assessment shall be "low" or higher. Whether the risk assignment is "low" or at some higher risk level depends on the projected life margin and the data dispersion.

3.3 Assessment of Risk Using a Combination of Real-time and Accelerated Test Data for Model Projections with a Universally Accepted Quantitative Relationship between Accelerated and Real-time Testing

If a combination of real-time and accelerated test data are used for model projections, the model projection methodology and use of accelerated test data have a sound technical basis, including all degradation modes, the quantitative relationship between real-time and accelerated testing has been established and is universally accepted by the space battery community, the risks associated with the assessment are given below. An acceptable approach to such model projection is to separate the eclipse season and solstice season components of life degradation by utilizing data from real-time testing and from accelerated tests, with variations in eclipse and solstice usage.

- If the real-time data demonstrate 35% of the mission life or longer without any cell failure, subject to the sample size considerations described below, and the projected life values are above the mission life requirement or goal, the risk assessment shall be "medium" or higher. Whether the risk assignment is "medium" or at some higher risk level depends on the projected life margin and the data dispersion.
- If the real-time data demonstrate 50% of the mission life or longer without any cell failure, subject to the sample size considerations described below, and the projected life values are above the mission life requirement or goal, the risk assessment shall be "low-medium" or higher. Whether the risk assignment is "low-medium" or at some higher risk level depends on the projected life margin and the data dispersion.
- If the real-time data demonstrate 65% of the mission life or longer without any cell failure, subject to the sample size considerations described below, and the projected life values are above the mission life requirement or goal, the risk assessment shall be "low" or higher. Whether the risk assignment is "low" or at some higher risk level depends on the projected life margin and the data dispersion.

4. Sample Size

The sample size and failure probability function can affect the required test duration.

- A baseline sample size was set at 20 as a compromise between lower test cost and more meaning statistics. Other sample sizes can be used.
- If the sample size is 20, the actual test duration without failure can be directly used for the life expectancy assessments described above.
- If the sample size, N, is not 20, the actual test duration without failure should be multiplied by a factor K for mission life expectancy assessments.
  - The reliability and confidence level for a test with N samples without failure for duration KT shall be equal to the reliability and confidence level for a test with 20 samples for duration T.
- If the failure probability function is not known, the use of a Weibull function is suggested to facilitate refinement of the failure probability function as more data are accumulated.

5. Conclusions

Verification guidelines for establishing lithium-ion life expectancy have been established for the TSAT mission. The guidelines cover three possible scenarios: (1) Real-time test data only; (2) Combination of real-time and accelerated test data for model projetions without universally accepted quantitative relationship; and (3) Combination of real-time and accelerated test data for model projections with a universally accepted quantitative relationship. For each scenario, the minimum amount of real-time data versus a minimum risk assignment is defined for the TSAT mission.

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The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Laboratory Operations supports the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual organizations:

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